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Factors Affecting Length of Herdlife in Purebred and Crossbred Dairy Cattle[1,2]

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ABSTRACT

The proportional hazards model with censoring was used to assess the effects of breeding value, disease, calving, size, and udder and lactation traits on length of herdlife of 3881 heifers in five herds. Data were recorded over 10 yr from three lines: a Holstein line, an Ayrshire-based line, and a crossbred line. Influences on survival were assessed from data collected at birth, 34, 50, and 82 wk, first freshening, and at 112 and 308 d postpartum. Median estimated herdlife (age at 50% culling) was 3.9 yr for animals alive at first freshening and increased to 4.3 yr for those that completed a first lactation (308 d postpartum). Herds differed greatly in the pattern of culling after freshening. Crossbred females had 21 wk longer median estimated herdlife than the mean of the purelines at 308 d postpartum. Individual milk yield was positively associated with longevity and had the greatest impact on length of herdlife. Abortion and fertility measured as days to last insemination were negatively associated with length of herdlife. Large heifers tended to have increased longevity. High feed intake postpartum was associated with reduced length of herdlife. Objective measures of conformation, which included measurements of the udder, were not important in determining herdlife.

INTRODUCTION

High milk yields in early adulthood are positively associated with length of herdlife after first parturition of dairy cattle. Herdlife is usually taken to refer to the average age at disposal of heifers surviving to calve once. Thus, longer herdlife reduces replacement costs and land requirements and leads to higher average milk yield through greater mean herd age and to a small improvement in genetic potential (8). Phenotypic correlations between first lactation milk yield and measures of longevity (e.g., herd days first to last calving or disposal, lactations initiated) have ranged from .13 to .43 and corresponding genetic correlations from .76 to .91 (9, 10, 21, 23). Attempts to improve the prediction of longevity by including conformation (6, 12, 24) or calving interval (21) have not been successful. Everett et al. (7) have shown an apparently contradictory negative genetic trend for survival in American breeds of dairy cattle over about a 20-yr period of selection for first lactation milk yield.

Dairy cows commonly live for 10 yr or more (1, 9, 15). Measuring survival to a fixed age is possible (19) but does not use all available herdlife information. The proportional hazards model has been widely used in the medical sciences for evaluating importance of prognostic and classification traits for survival. This analytical method utilizes all available lifetime information on living as well as deceased subjects. Appraisal of the influence of traits in the rearing period on length of herdlife in dairy

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cattle is not available in the literature. Suitable data would require recording of detail data from birth until removal from the herd or death.

The National Cooperative Dairy Cattle Breeding Project (NCDCBP) was established in 1972 to evaluate whether pureline selection for protein yield and a systematic crossbreeding system improve lifetime performance of dairy cattle (20). Herds were maintained at five Agriculture Canada research stations. An extensive set of traits was recorded from conception to culling and provide suitable data for evaluating effects of these traits on longevity. The objective of this study was to assess the utility of applying the proportional hazards model to these data and to determine whether traits measured in the rearing period influenced length of herdlife.

MATERIALS AND METHODS

Animals and Data

Data on 3881 NCDCBP females born from January 1972 to October 1981 were included in the study. The five herds involved in the study were located at Charlottetown, Prince Edward Island; Lennoxville, Quebec; Lethbridge, Alberta; Normandin, Quebec; and Ottawa, Ontario (Table 1). The animals were housed indoors throughout the year at Ottawa, but conventional systems of housing with outside lots and pastures existed at the other locations.

Two closed lines were established in 1972 and 1973 and were selected for increased milk protein yield. Foundation animals and matings were described by Lee et al. (18). The H line was developed from various Holstein strains. The A line was synthesized from Ayrshire cattle with contributions from Brown Swiss, Norwegian Red, and Finnish Ayrshire bulls. Foundation Holstein and Ayrshire cattle had previously been selected for increased total solids yield (Hickman, 1971). From 1974 to 1978, reciprocal crosses of each of the two lines were made to produce the females of a crossbred line (C line). Crossbred females were mated to first generation crossbred bulls produced from the same elite parents of pureline young bulls to investigate the merits of this system of selection and crossbreeding for improving lifetime productivity.

TABLE 1. Number of animals by year, herd, and line.

Year of birth	Herd × line											Line			Total per year
	Charlotte-town		Leth-bridge		Norman-din		Ottawa			Lennox-ville					
	A[1]	C	H	C	A	C	H	A	C	H	C	H	A	C	
Year															
1972	11	0	14	0	0	0	60	64	0	24	0	98	75	0	173
1973	14	0	42	0	35	0	110	96	6	48	0	200	145	6	351
1974	16	0	39	0	29	4	138	109	8	81	2	258	154	14	426
1975	17	2	37	10	22	8	108	76	48	49	15	194	115	83	392
1976	15	9	32	13	25	14	116	89	61	63	16	211	129	113	453
1977	13	8	26	10	19	14	113	73	86	39	30	178	105	148	431
1978	15	8	20	14	22	12	109	59	113	28	32	157	96	179	432
1979	15	11	29	17	17	16	82	60	117	32	21	143	92	182	417
1980	7	8	31	13	29	15	109	60	92	45	22	185	96	150	431
1981[2]	17	12	15	14	16	16	89	42	86	44	24	148	75	152	375
Totals	140	58	285	91	214	99	1034	728	617	453	162	1772	1082	1027	3881

[1] H = Holstein line, A = Ayrshire-based line, C = Crossbred line of H × A and A × H and C × C.

[2] January to October.

The experimental protocol specifying guidelines for feeding, breeding policies, and culling criteria was followed at all stations. Calves were separated from their dams within 24 h of birth and reared individually for the first 8 wk in calf stalls on a whole milk feeding programme with limited intake. Calf starter-grower was limited to a maximum of 2.5 kg/d for the first 34 wk and 1.8 kg/d from 34 to 50 wk. Forage feeding began by 8 wk. Individual feed consumption and weight gain were recorded on all heifers from 26 to 34 wk of age. Thereafter, hay or silage was available ad libitum until 2 wk before first calving. Heifers were observed for estrus twice daily. Artificial insemination commenced at first estrus after 50 wk of age or 56 d postpartum. Prior to 1978, heifer lactations were terminated if daily milk yield dropped below 9 kg. A 5 kg limit was used in later years. Culling occurred when an animal left a herd for whatever reason except to be transferred to one of the other herds. Mandatory culling was practiced on heifers not pregnant by 82 wk of age and cows not pregnant by 280 d postpartum. Modest discretionary culling was practiced on animals with deficient or seriously impaired performance due to low milk production, poor udder suspension, or debilitating disease or injury. Any culling required to accommodate newly calved cows in milking facilities was based on estimated genetic merit for protein yield.

Traits recorded were described by Hocking et al. (12) and are listed in Table 2. Seven data sets were created by considering animals alive at birth (BRTH), 34 (WK34), 50 (WK50), and 82 (WK82) wk of age, at first freshening (FFR), and at 112 (PP112) and 308 (PP308) d postpartum. Data on growth, reproduction, production, udder measurements, calving traits, nutrient consumption, disease frequency, and sire's estimated breeding value (SEBV) for milk yield and composition were available. The SEBV lactation traits were included to determine if pedigree genetic merit influenced survival. The survival times of animals in each data set were examined for relationships with the various traits that had been measured up to that time (Table 2).

Statistical Methods

Many animals were still alive in October 1981 when the data set was created and their ultimate lengths of life were unknown. Such observations were said to be censored. We sought to use all available data on traits measured and concurrent classification factors (i.e., line, birth year, herd) to evaluate their importance for survival. The proportional hazards model (3) used both censored and complete data to evaluate the effects of covariates (traits and factors) on survival. Culling (hazard or risk) rate rather than actual time to culling (survival time) was used to measure survival. The model may be written as:

$$h\,(t, x) = h_0(t)\,\exp\,(B'\,x)$$

where $h\,(t, x)$ is the culling rate of an individual at age t with covariate vector x; $h_0(t)$ is an underlying unknown age specific culling function independent of x, i.e., a baseline culling function for a hypothetical individual with $x = 0$; and B is a corresponding vector of unknown parameter values specifying the effect of the covariates on survival. The function $h_0(t)$ can be chosen from among formally described mathematical distributions with parameters (25) but is left unspecified in the Cox method (4).

The proportional hazards model is based on three principal assumptions. First, the ratio of hazard functions for any two individuals of the same age with covariate vectors x_1 and x_2, respectively, is $\exp\,[B'\,(x_1 - x_2)]$. This ratio, the relative culling risk (RCR), is independent of age (t). This assumption arises because of the proportionality (multiplicative relationship) between $h_0(t)$ and the log-linear function of the covariates. Second, the ratio of hazards functions for ages t_1 and t_2 of any animal can be written as $h_0(t_1)/h_0(t_2)$. The third assumption of the model is that covariates are linearly related to the hazard (culling) rate on the exponential scale. In terms of logarithms of the hazard function, at any given age:

$$\ln[h(t, x)/h_0(t)] = B'\,x$$

Estimation of B was by the method of Cox (4). It was necessary to assume that censoring occurred at random and was not based on covariate values. With year of birth in the model this was not strictly true. Culling was assumed to be independent of the covariates (e.g., heifers were not culled on the basis of their half sister's records). The culling decision

TABLE 2. Total number of animals and means and standard deviations of traits defining the initial models for seven data sets.

Trait	Rearing: Birth		Rearing: 34 wk		Rearing: 50 wk		Rearing: 82 wk		First lactation: Fresh		First lactation: 112 d lactation		First lactation: 308 d lactation	
	X̄	SD	X̄	SD	X̄	SD	X̄	SD	X̄	SD	X̄	SD	X̄	SD
Birth														
SEBV[1] milk, kg	286	233	292	239	290	241	291	248	294	252	322	265	324	262
SEBV protein, %	−.11	.07	−.12	.07	−.12	.07	−.12	.08	−.12	.08	−.13	.08	−.13	.07
SEBV fat, %	−.19	.14	−.20	.14	−.20	.15	−.20	.15	−.20	.15	−.21	.15	−.21	.15
SEBV lactose, %	−.03	.06	−.03	.06	−.03	.06	−.03	.06	−.04	.06	−.04	.06	−.04	.06
Birthweight, kg	38	6	38	6	38	6	38	6	38	6	38	5	38	6
Growth														
Weight, kg			206	28	289	35	434	50	438	54	431	51	507	60
Heart girth, cm			131	6	151	6	174	7	178	8	178	7	184	8[3]
Withers height, cm			104	5	113	5	123	5	126	5	126	5	128	5[3]
Shoulder to hook, cm			84	5	92	5	104	5	105	5	107	6	108	6[4]
Rump length, cm			34	3	38	3	43	3	44	3	45	3	45	3[4]
Width of hooks, cm			33	2	39	3	46	3	48	3	48	3	48	3[4]
Width of chest, cm			30	3	35	3	42	4	42	4	42	4	41	4[4]
Depth of chest, cm			50	3	57	3	65	3	67	3	67	3	67	3[4]
Feed intake, TDN[2]			198	30	199	30	199	31	199	32	496	92	496	91
Disease frequency, %														
Other			.2	1.0	.4	1.1	.4	1.1	.4	1.1	.5	1.2	.6	1.3
Respiratory			1.2	2.3	1.2	2.3	1.2	2.2	1.2	2.1	1.1	2.1	1.0	2.0
Metabolism			.8	1.5	.8	1.5	.8	1.5	.8	1.5	.8	1.4	.8	1.4
Reproduction							.1	.4	.2	.5	1.0	1.7	1.2	2.0
Mastitis									<.1	.2	.4	1.2	.7	1.6
Reproduction														
No. estrous cycles					1.2	1.3								
No. services							1.9	1.3			1.4	.7	2.1	1.4
"Hard" inseminations							.11	.01					.07	.01
Age first heat, d							379	29					74	22[5]
Age last insemination, d							408	57					111	55[5]
Calving														
Age fresh, d									678	48	677	48	676	47
Calf condition: normal									.72	.01	.72	.01	.72	.01
Calf condition: breech									.17	.01	.17	.01	.17	.01
Calf condition: difficult									.11	.01	.11	.01	.11	.01
Retained placenta (Yes/No)									.11	.01	.10	.01	.10	.01
Mutiple births (Yes/No)									.002	.001	.001	.001	.001	.001
Abortion (Yes/No)									.01	.002	.01	.002	.01	.002
Udder														
Fore teat length, cm									4.8	1.0	4.4	.8	4.4	.8
Fore teat diameter, cm									2.4	.5	2.0	.4	2.0	.4
Rear teat length, cm									4.1	.8	3.8	.8	3.8	.8
Rear teat diameter, cm									2.4	.5	2.0	.4	2.0	.4
Fore rear teat distance, cm									11.7	2.1	9.4	1.8	9.3	1.8
Udder height, cm									54	5	57	5	57	5
Fore:rear udder yield											.45	.05[4]	.45	.05[6]
Milking speed, kg/3 min											11.5	3.7[4]	11.6	3.6[6]

Lactation									
Milk yield, kg						1759	405	3801	1167
Protein, %						3.14	.25	3.26	.22
Fat, %						3.51	.77	3.61	.63
Lactose, %						5.27	.23	5.20	.19
Lactation length, d								277	50
Total	3881	3147	2997	2601	2367	1662[7]		1625	
Culled	2328	1890	1855	1740	1562	1145		1156	
Censored, %	40	40	38	33	34	31		29	

[1] Sire's estimated breeding value.

[2] Total digestible nutrients consumed 8 to 16 wk (for data available at 34, 50, 82 wk, and fresh) and 56 to 112 d postpartum (for data available at 112 and 308 d lactation).

[3] 280-d data.

[4] 112-d data.

[5] Days postpartum.

[6] On 1457 records.

[7] There were 1854 animals for all traits except milking speed.

was based solely on the performance of the individual animal. Genetically related individuals have correlated trait vectors, but in most cases have independent sets of other factors affecting survival. A comprehensive description of the model and estimation of parameters is given by Kalbfleisch and Prentice (16).

Computing Procedures

Each of the seven data sets were analyzed separately using the program BMDP2L (14). The full set of potential covariates (Table 2) was included in the first model for each data set. The covariates that did not affect herdlife ($P<.05$) were omitted and the model refitted. This process of covariate deletion and parameter reestimation continued provided that the reduction in the log likelihood of the current model compared with the first model was not significant ($P<.05$). Two or three iterations were required to obtain the final model for most analyses. Separate analyses were completed with and without the SEBV milk yield and composition traits being allowed to enter the model. For the WK34, WK50, and WK82 data sets, with SEBV traits excluded, the effects of herd, year, and breed, if significant on the first run, were forced into the model and a forward stepwise procedure adopted to select the remaining covariables. Departure from a slope of unity in the regression of the cumulative hazard function of the residuals against the residual itself indicated a lack of fit of the model (17).

Differences between discrete (classification factor) covariates were evaluated by a t test using the standard error of the difference computed from the estimated variance-covariance matrix of B. Tests presented in tables are for a contrast with a single suitable base (year, 1972; herd, Ottawa; line, H line; and calving, normal). The RCR values for continuous covariables were calculated for an increase of one standard deviation above the mean value (RCR = 1.00). For each final model, survival curves were plotted for the mean covariate vector, for each fixed discrete covariate, and for plus and minus one standard deviation of each continuous covariate. Age at 50% culling [median estimated herdlife (MEHL), i.e., half-life] from these plots was obtained as a convenient way of comparing the relative importance of the covariates. The MEHL were computed on the basis of equal weighting among the fixed years and herds rather than by weighting according to their frequency in the population.

The statistical procedure estimates effects of covariates on risk of culling. Negative parameter estimates (B_i) and RCR's <1.0 are desirable, i.e., culling is reduced and length of herdlife increased. This, for continuous covariates, if $B < 0$, survival rate increases, and if $B > 0$, then survival rate decreases.

RESULTS AND DISCUSSION

Overall Survival

Trait means and standard deviations, the number of observations, number culled, and proportion censored (i.e., alive at the end of the data collection period) for each data set are presented in Table 2. Censoring ranged from 29 to 40% and represented a considerable amount of data that cannot be used in traditional analyses. Plots (not shown) of the cumulative hazard function of residuals showed excellent agreement with the proportionality assumption. The coefficients of the covariates that significantly affected herdlife and their standard errors, the relative culling risk, and half lives are presented in Tables 3 to 6. The method appears to be sensitive, since several continuous traits retained in the models have a relatively small effect (5 to 10 wk) on half life.

Estimated MEHL at birth (Table 3) was 185 wk (3.6 yr) or about 1.5 lactations. Heifers freshened at an average age of 97 wk or 1.9 yr. The MEHL of animals alive at FFR (Table 5) had increased to 203 wk (3.9 yr) and at 308 d postpartum to 225 wk (4.3 yr). Increase in MEHL between freshening and 308 d postpartum (Table 6) was only half (22 wk) the length of the 308 d lactation record. The estimated productive life of a heifer at FFR was 106 wk and had decreased to 84 wk by PP308. Survival curves based on final models at birth, WK50, FFR, and PP308 are given in Figure 1. The survival curve for data at birth illustrates the importance of early calfhood losses (nearly 8%) in the first 6 mo (12) compared with a total loss of 20% in the first 2 yr.

The SEBV for milk yield was retained in all models except for PP112 and PP308 when a record of individual milk yield was available. When SEBV traits were omitted as possible covariates, the final model contained the same variables except at WK34 and WK50, where a measure of skeletal size (and herd for WK34) was included. At FFR, line was not included in the final model when SEBV traits were precluded as covariates but was retained in all other analyses. In general, the effect of omitting SEBV traits on the estimates of the other coefficients retained in the model was negligible. Only the results allowing SEBV traits to be retained are presented in Tables 3 to 6. Omitting SEBV milk yield greatly decreased regression coefficient estimates for the early years when many bulls were introduced from a wide range of commercial sources and increased the estimated coefficients for the later years. Genetic differences among bulls bred in the later years exhibited considerably less within-line genetic variation. Improved calf husbandry may have increased the estimated herdlife for later years of the experiment. The reduction in the "dry off" criterion from 9 to 5 kg in 1978 may also have affected survival since before that time a modest proportion of heifers were dried off before 112 d postpartum.

Herd Influences

Differences in survival among herds at FFR, PP112, and PP308 reflect large differences in the pattern of culling and length of herdlife (Figures 2a,b). The MEHL of survivors at PP308 was low at Lethbridge (180 wk) and high at Lennoxville (270 wk), a difference of almost two lactations (Table 6). Culling after first lactation reflected different circumstances among the herds (Table 5). The heavy losses at Normandin after 112 d postpartum resulted from adverse effects of transferring heifers to a second barn with less favorable conditions at this point in first lactation. Stable herd size and few heifer losses from disease or reproduction required culling low yielding females to permit replacements to enter the herd at Lethbridge. Herd size at Ottawa was expanding in the early years, which limited discretionary culling; furthermore, there was a lower rate of producing replacements due to above average death losses of young calves. Discretionary culling to accommodate newly calved cows, when practiced, was done within line to maintain the relative proportions of pureline and crossline animals at each station.

TABLE 3. Proportional hazards model of relative survival time for heifers alive at birth and 34 wk.

	Birth				34 Wk			
	Coefficient				Coefficient			
Covariate	*B*	SE[1]	Relative culling risk[2]	Half-life (wk)[3]	*B*	SE	Relative culling risk	Half-life (wk)
Year								
1972	.05	.08	1.00	190				
1973	.09	.06	1.04^{NS}	173				
1974	.09	.06	1.04^{NS}	173				
1975	.03	.08	.98^{NS}	183				
1976	.08	.06	1.04^{NS}	173				
1977	.14	.06	1.10^{NS}	170				
1978	.22	.07	1.20^{NS}	163				
1979	.03	.09	.98^{NS}	183				
1980	−.39	.15	.64**	225				
1981	−.24	.18	.75^{NS}	208				
Breed								
H	.05	.03	1.00	180	.02	.03	1.00	188
A	.11	.04	1.06^{NS}	173	.15	.03	1.14*	178
C	−.16	.04	.81**	198	−.18	.04	.82**	205
Birth weight, kg	.01	.004	.94**	190				
SEBV[4] milk, kg × 10^{-3}	−.33	.10	.93**	190	.39	.10	.91**	195
Disease: other					.05	.02	1.06*	183
MEHL				185				188

[1] Standard error of parameter estimates.

[2] Relative culling risk, NS, not significantly ($P>.05$) or *significantly ($P<.05$) and **($P<.01$), respectively, different from 1.00. By definition, first of each discrete classification variable has relative culling risk of 1.00.

[3] Age at culling.

[4] Sires estimated breeding value.

TABLE 4. Proportional hazards model of relative survival time for heifers alive at 50 and 82 wk.

	50 Wk				82 Wk			
	Coefficient				Coefficient			
Covariate	B	SE[1]	Relative culling risk[2]	Half-life (wk)[3]	B	SE	Relative culling risk	Half-life (wk)
Line								
H	.02	.03	1.00	188				
A	.15	.04	1.13*	178				
C	−.17	.04	.82**	205				
Line of service sire × line of mate								
H × H					.02	.05	1.00	183
A × A					−.02	.05	.97^NS	190
H × A					.09	.07	1.08^NS	183
A × H					.12	.08	1.11^NS	183
C × C					.21	.06	.80**	208
Age first estrus, d					.003	.001	.92**	195
Age last insemination, d					.005	.0005	1.32***	170
Withers height, cm					−.02	.01	.92**	195
SEBV milk kg × 10^{-3}	−.4345	.1026	.90**	198	−.41	.11	.90***	195
Chest width, cm					−.03	.01	.92***	195
MEHL				190				190

[1] Standard error of parameter estimates.

[2] Relative culling risk, NS, not significantly ($P>.05$) or *significantly ($P<.05$) and **($P<.01$), respectively, different from 1.00. By definition, first of each discrete classification variable has relative culling risk of 1.00.

[3] Age at culling.

[4] Sires estimated breeding value.

TABLE 5. Proportional hazards model of relative survival time for heifers alive at first freshening and those making a 112-d lactation record.

Covariate	First freshening				112 d Postpartum			
	Coefficient		Relative culling risk[2]	Half-life (wk)[3]	Coefficient		Relative culling risk	Half-life (wk)
	B	SE[1]			*B*	SE		
Herd								
Ottawa	−.02	.05	1.00	210				
Charlottetown	.01	.09	1.03^{NS}	203				
Lethbridge	.25	.08	1.29**	190				
Normandin	.11	.09	1.14^{NS}	195				
Lennoxville	−.35	.08	.72***	245				
Breed								
H	.04	.04	1.00	203				
A	.09	.04	1.06^{NS}	198				
C	−.13	.05	.85*	220				
Calving								
Normal	−.03	.05	1.00	203				
Difficult	−.13	.10	.91^{NS}	213				
Breech	.16	.06	1.21**	193				
Placenta								
Tetained	.11	.04	1.24**	190				
Not retained	−.11	.04	1.00	203				
Abortion								
Yes	.29	.14	1.79*	170				
No	.29	.14	1.00	170				
Shoulder to hook, cm	−.02	.01	.90***	213				
SEBV[4] milk, kg × 10^{-3}	−.43	.11	.90***	213				
Feed intake, TDN[5]					.02	.001	1.17*	190
Milking rate, kg/3 min					−.03	.01	.89**	203
Milk, kg × 10^{-3}					−1.39	.15	.57***	243
Protein, %					−.45	.13	.89***	203
Disease: metabolic	.06	.02	1.09**	198	.07	.02	1.10**	190
MEHL				203				195

[1] Standard error of parameter estimates.

[2] Relative culling risk, NS, not significantly ($P>.05$) or *significantly ($P<.05$) and **($P<.01$), respectively, different from 1.00. By definition, first of each discrete classification variable has relative culling risk of 1.00.

[3] Age at culling.

[4] Sires estimated breeding value.

TABLE 6. Proportional hazards model of relative survival time for heifers completing a 112 to 308 d first lactation period.

Covariate	Coefficient B	SE[1]	Relative culling risk[2]	Half-life (wk)[3]
Year				
1972	−.08	.09	1.00	235
1973	−.05	.07	1.03NS	230
1974	.02	.07	1.10NS	220
1975	.07	.10	1.15NS	215
1976	−.19	.09	.90NS	245
1977	−.09	.09	.99NS	235
1978	.31	.12	1.48*	235
Herd				
Ottawa	−.19	.06	1.00	245
Charlottetown	−.20	.12	1.00NS	245
Lethbridge	.89	.12	2.95***	180
Normandin	−.01	.11	1.20NS	223
Lennoxville	−.49	.09	.74**	270
Line of service sire × line of mate				
H × H	.24	.06	1.00	208
A × A	.05	.07	.83NS	220
H × A	.17	.09	.93NS	213
A × H	−.35	.11	.55***	258
C × C	−.10	.08	.71***	235
Calving				
Normal	−.001	.06	1.00	225
Difficult	−.17	.11	.85NS	243
Breech	.17	.07	1.18*	213
Abortion				
Yes	.38	.16	2.12*	185
No	−.38	.16	1.00	225
Feed intake, TDN[4]	.002	.001	1.16*	215
Calving to first estrus, d	−.005	.002	.90**	235
Calving to last insemination, d	.01	.001	1.47***	200
Milk, kg × 10^{-3}	−.56	.05	.52***	285
Protein, %	−.48	.16	.90**	235
Frequency reproductive disease	.04	.02	1.09*	218
Frequency metabolic disease	.06	.02	1.09**	215
SEBV[5] fat, %	.67	.24	1.10**	218
MEHL				225

[1] Standard error of parameter estimates.

[2] Relative culling risk, NS, not significantly (P>.05) or *significantly (P<.05) and **(P<.01), respectively, different from 1.00. By definition, first of each discrete classification variable has relative culling risk of 1.00.

[3] Age at culling.

[4] Total TDN consumed 56 to 112 d postpartum.

[5] Sires estimated breeding value.

Line Influences

In all the analyses, estimated herd lives for C line heifers were at least 17 wk longer (P<.05) than for pureline heifers mated within line. The greatest differences were observed in the WK82 and PP308 analyses. The A line heifers were culled more severely (P<.05) after 34 and 50 wk, possibly from their inability to compete effectively in group housing conditions. The H and A line heifers pregnant to sires of the

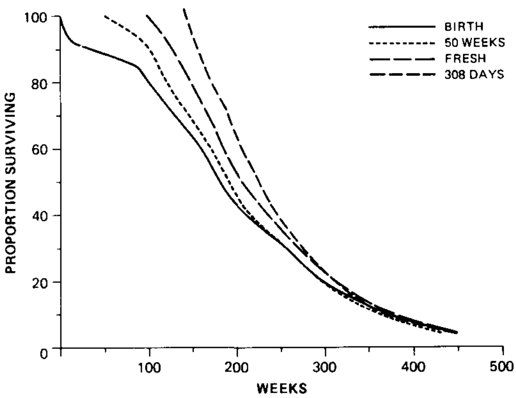

Figure 1. Estimated survival curves for animals alive at birth, 50 wk of age, first freshening, and 308 d postpartum.

alternative breed at WK82 were no more likely to be culled than heifers assigned to pure matings (Table 4). At PP308 H line cows mated to A line sires (A × H) had a 50 wk longer MEHL (P<.01) (Table 6) than H line cows mated to H line sires (H × H). It is difficult to explain this result. The advantage in survival of crosses resulting from F_1 male by C line female matings [the reciprocal hybrid male crossbreeding system (22)] over the mean of pureline H and A line matings was 21 wk, at completion of 308 d lactation. The net effect of such a crossbreeding system in economic terms is important and warrants further study. Similar results may be expected from line crosses within breeds. Breed survival curves at birth and 308 d postpartum are shown in Figures 3a and b.

Important Traits

Milking speed was positively related to herdlife (P<.01) in data available at 112 d (Table 5), perhaps indicating faster milking cows were less likely to be culled. Milking speed was not retained in the model at PP308. Milk yield had an important (P<.001) effect on postpartum survival. An increase of one standard deviation in individual milk yield raised MEHL by 48 and 60 wk, respectively, in animals alive at PP112 and PP308 (Tables 5 and 6). The effect of SEBV milk yield was highly significant at all ages to freshening, but in contrast to individual milk yield of cows, an increase of one standard deviation in the SEBV milk yield resulted in only a 5 to 10 wk increase in MEHL. A measure of skeletal size was retained in the models at WK34 and WK50 (Tables 3 and 4) when SEBV milk was precluded from the model, suggesting some relationship between body size and milking potential. Age at first estrus, age at last insemination and withers height were significant (P<.05) at WK82 (Table 4) suggesting that larger, possibly more mature, heifers had higher pregnancy rates and survived longer.

Discretionary culling in this experiment was primarily on 308 d protein yield in first lactation. As expected, protein percentage was retained in the models at PP112 and PP308; however, the estimated effect on herdlife was

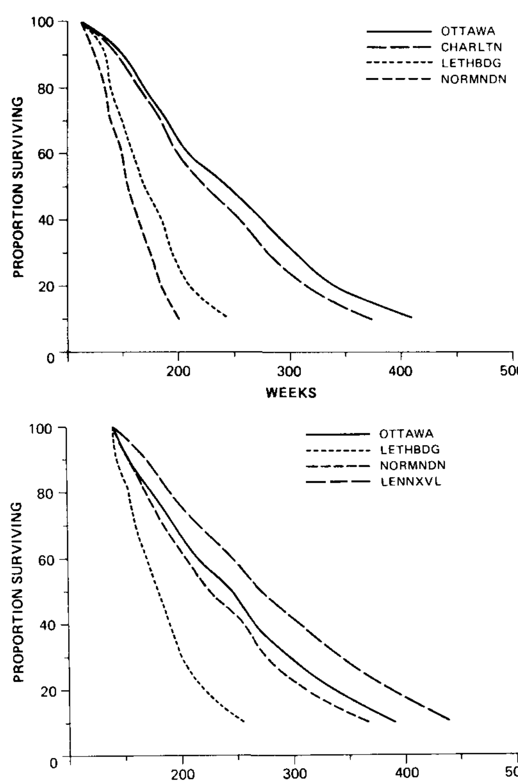

Figure 2. Estimated herd survival curves for animals alive at a) 112 d and b) 308 d postpartum. Curves for Lennoxville a) and Charlottetown b) were similar to those for Ottawa and were not drawn for clarity.

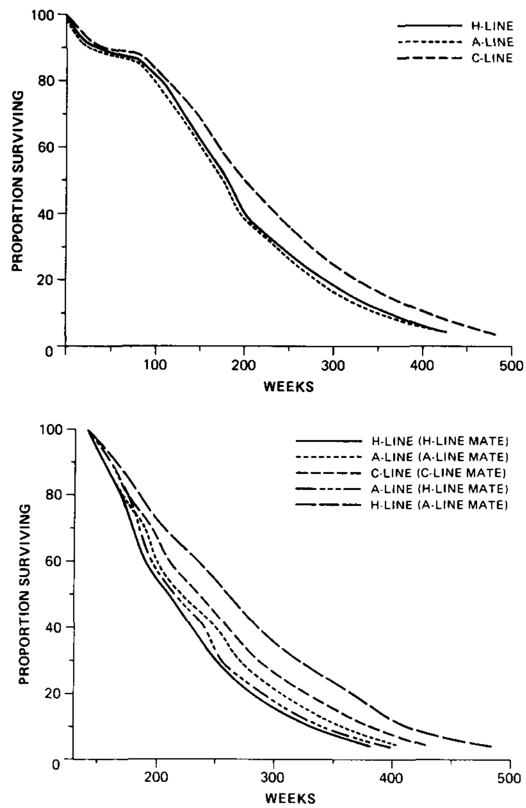

Figure 3. Estimated survival curves of lines of females at a) birth and b) 308 d postpartum.

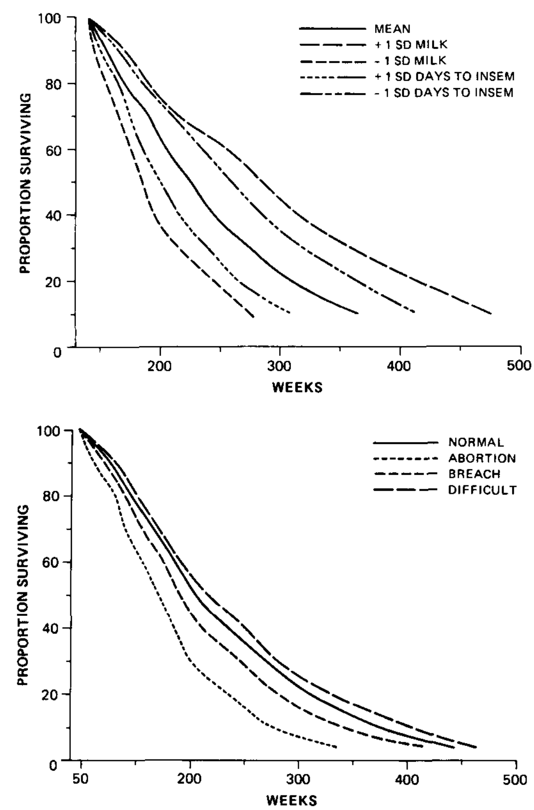

Figure 4. Estimated survival curves at 308 d for hypothetical animals with a) mean covariate vector plus or minus one standard deviation for milk yield and days to last insemination and for b) different types of calving.

small, probably because variation in protein content was small (Table 2). Curiously, SEBV fat percentage was retained at PP308. It is possible that daughters of bulls with higher EBV for fat percentage have a greater energy output, may be more difficult to get pregnant (2, 5), and thus, more likely to be culled. Number of days from freshening to last insemination (Table 6) and occurrence of an abortion were of almost equal importance to milk yield in influencing herdlife at PP308. Abortion also reduced survival time at FFR (Table 6). The large effects of milk yield and days to last insemination on survival are illustrated in Figure 4a for animals completing a 308-d lactation record. The effect of an abortion on subsequent survival of cows that calved once and completed a lactation is shown in Figure 4b.

Age at last insemination for survivors at WK82 and days from freshening to last insemination for cows alive at PP308 had similar large effects on RCR and MEHL (Tables 4 and 6). Older heifers at last insemination indicated poor fertility and a substantially reduced herdlife. Age at first estrus for WK82 data (Table 4) and days to first estrus postpartum for PP308 data (Table 6) had a small effect on culling (5 to 10 wk longer MEHD) with higher values having a positive effect on survival, i.e., precocious sexual activity was undesirable. Early signs of estrus were expected to reduce culling by providing a longer insemination period. It is possible that pregnancies from early inseminations are more likely to undergo spontaneous resorption.

Above average feed intake from 56 to 112 d postpartum was associated with decreased MEHL (Tables 5 and 6). Because the major output variables are represented in the model, extra feed energy must either be used for fat deposition or heat loss. Excessive weight gain at the time of first artificial insemination has been reported to be associated with low pregnancy rates (5). Excessive fatness from high energy intake above requirements may also result in difficult calving and unproductive second lactations typical of the "fat cow syndrome".

Small effects of 5 to 10 wk on half-life were shown for several covariates. Retained placenta had a negative effect ($P<.01$) at FFR (Table 5) but not a PP308 (Table 6); suggesting no long-term detrimental effect. Difficult calving had no significant effect on estimated herdlife while a breech presentation had a small but negative ($P<.01$) effect at FFR and PP308 (Figure 4b). Body length from shoulder to hook slightly increased ($P<.001$) survival time at FFR. As a measure of skeletal size, it indicates that mature (i.e., larger) heifers had a longer MEHL perhaps through greater potential milk yield but more likely because of reduced calving stress.

The disease code "other" includes accident and physical injury and probably accounts for its retention at 34 wk (Table 3). Metabolic disease (milk fever, displaced abomasum, etc.) had a similar negative effect ($P<.001$) at FFR, PP112, and PP308 (Table 5 and 6). Reproductive disorders, mostly uterine infections, were negatively associated ($P<.05$) with survival time at PP308 only and has a relatively small effect compared with service interval (days to last insemination). Notably, objective measures of conformation, even measurements of the udder, were not an important influence on herdlife.

Conclusion

Results demonstrate that the longevity of individual animals is influenced by their biological makeup, the husbandry conditions to which they are exposed, and the economic and physical requirements of the production system. Prediction of longevity should be treated as a sequential process. Largely different sets of traits and conditions seem to influence survival at the individual stages. From our analyses the critical points appear to be early calfhood, first conception, first parturition, and second conception. Beyond early calfhood, reproductive difficulties pose the greatest hazard to survival. Lactation yield potential or actual lactation performance offers the greatest enhancement to longevity.

Early calf losses and heifer infertility reduce survival to first freshening and emphasize the importance of heifer rearing in the dairy herd. Herdlife after first calving is primarily determined by milk production, expression, and detection of estrus and success of insemination. Conformation, size, and calving difficulty have minor effects on survival from first calving to second parturition. Genetic effects on yield and survival influence herdlife of individual cows but environmental effects have the greatest impact. Positive manipulation of feeding, husbandry, and management programs can enhance longevity.

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